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Heterogeneous Multiscale Method for Composite Materials and Probability-Based Explanation of Size Effect in Localized Failure

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Abstract :

In this work we review the main issue pertinent to evaluation of integrity and durability of large structures built of heterogeneous composite materials. The applications concern the domain of energy production, with both currently dominant French systems (nuclear power plants) and the future renewable energy sources (giant offshore wind turbines), as well as the transportation domain (large aeroplanes built of composites, as alternative to Boeing 787 Dreamlinear). The common feature of these problems is shear structural size and excessive cost which exclude the full experimental validation of the structure integrity and safety. We show that the state-of-the-art advances in heterogeneous multiscale methods can be brought to bear upon this class of problems, providing the full understanding of the potential failure modes of the given system, along with the very detailed simulation of extreme conditions brought by man-made and natural hazards . We also show that such advanced state of computational methods can be successfully combined with probability computations in order to provide a detailed interpretation of tests on structures under heterogeneous stress field. The proposed approach offers a clear explanation of the size effect, which implies that the structure size changes the dominant failure modes.

1. Introduction

This paper deals with important challenge on quantifying durability, life-time integrity and safety against failure of massive composite structures under extreme conditions. The illustrative applications come from the area of energy production systems, with both currently dominant nuclear source in terms of nuclear power plant or renewable energy sources in terms of giant wind turbines, as well as from the domain of transportation in terms of the European answer to currently largest plane entirely built of composties, Boeing 787 Dreamliner (see Figure 1). Special attention is given to costly massive structures with 'irreplaceable' components, which are characterized by a number of different failure modes that require the most detailed description and interaction across the scales. We would like to significantly improve the currently dominant experimental approach, and thus accelerate innovations in this domain. Yet, this cannot be done only by experiments, due to the shear size of the structure, and often a prohibitively high cost and time delay related to such experiments.

Figure 1. Integrity and durability of (costly) massive composite structures: a) nuclear power plant both existing PWR and new EPR systems - stringent requirement on waterproof containment structure of CBFR composites; b) (European answer to) Boeing 787 Dreamliner, the most fuel-efficient aircraft built of CFRP composites – new requirement on no-return-to-hub for crack reparation; c) large offshore wind-turbine with CFRP composites blades and deep-sea CBRF composites support – requirement of durability and integrity to guarantee operational capabilities under extreme weather conditions for the largest possible offshore turbine blades (larger than A380 wings span).

2. Main Objectives

The main objective is development of novel Heterogeneous^2 Multiscale Method capable of representing strain field heterogeneities induced by evolution (and interaction) of localized failure mechanisms in massive structure, pertaining to micro scale (FPZ-fracture process zone), macro scale including softening (macro cracks) and non-local macro scale (bond-slip for long fiber reinforcement). The objective of Heterogeneous^2 Multiscale Method is also to provide capabilities for quantifying the risk of premature localized failure through probability description of initial defects (microstructure heterogeneity) and uncertainty propagation through scales. The novel scientific concept to be explored pertains to multiscale formulation and solution of coupled nonlinear mechanics-probability problem replacing the standard homogenization approach that can only provide average (deterministic) properties of heterogeneous composites. This concept is of interdisciplinary nature with Mechanics (defining probability distribution) and Applied Mathematics (providing uncertainty propagation) combined in order to capture the influence of heterogeneities and fine scale defects on premature failure.

The most important challenge concerns the ability to provide the sound, probability-based explanation of size effect (with different failure modes observed for different size specimens and real structure built of the same composite materials). The biggest potential gain concerns changing the validation procedures for massive structures that are beyond the size suitable for testing at present. The scientific gains concern providing the Heterogeneous^2 Multiscale Method that connects computations with design studies (optimization), testing (identification) and safety verification (monitoring) of massive composite structures. The scientific gains also concern further placing the proposed method within multiphysics framework, along with the original use of goal oriented error estimates to provide sufficiently reliable interpretation of extreme conditions (e.g. fluid or heat flow) and the code-coupling software implementation to quickly integrate existing simulation codes within such a framework.

The main technological gain is in development of the open source computational tools that can speed-up testing, decision-making and innovation in complex composite systems. Two model problems of composites with great application potential will be examined. First pertains to cement-based fiber reinforced (CBFR) composites, which will allow for validation of our method against recently completed experimental program in French excellence project

ECOBA. Second model of carbon fiber reinforced polymers (CFRP) that can be validated in collaboration with center for composites testing at Université Technologie Compiègne.

Further details are given in our recent works (Ibrahimbegovic et al. [1.17]).

3. Bibliographie

[1] Ibrahimbegovic A., D. Markovic, Strong coupling methods in multi-phase and multi-scale., *Comp. Meth. Appl. Mech. Eng.*, 192, 3089-3107, (2003)

[2] Ibrahimbegovic A., D. Brancherie, Combined hardening and softening constitutive model for plasticity: precursor to localized failure, *Comp. Mech.*, 31, 88-100, (2003)

[3] Ibrahimbegovic A., A. Delaplace, Microscale and mesoscale discrete models for dynamic fracture of structures, *Comp. Struc.*, 81, 1255-1265, (2003)

[4] Ibrahimbegovic A., D. Markovic, F. Gatuingt, Constitutive Model of Coupled Damage-Plasticity and Its Numerical Implementation, *Revue euro. élém. finis*, 12, 381-405, (2003)

[5] Ibrahimbegovic A., C. Knopf-Lenoir, A. Kucerova, P. Villon, Optimal design and optimal control of structures undergoing finite rotations, *Int. J. Num. Meth. Eng.*, 61, 2428-2460, (2004)

[6] Ibrahimbegovic A., I. Gresovnik, D. Markovic, S. Melnyk, T. Rodic, Shape optimization of two-phase material with microstructure, *Eng. Comp.*, 22, 605-645, (2005)

[7] Ibrahimbegovic A., S. Melnyk, Embedded discontinuity finite element method for modeling of localized failure in heterogeneous materials with structured mesh: an alternative to extended finite element method, *Comp. Mech.*, 40, 149-155, (2007)

[8] Ibrahimbegovic A., P. Jehel, L. Davenne, Coupled damage-plasticity model and direct stress interpolation, *Comp. Mech.*, 42, 1-11, (2008)

[9] Ibrahimbegovic A., G. Herve, P. Villon, Nonlinear impact dynamics and field transfer suitable for parametric design studes, *Eng. Comput.*, 26, 185-204, (2009)

[10] Ibrahimbegovic A., A. Kucerova et al., 'CE structures: multiscale damage representation, identification..', in 'Damage asses.', Springer, 1-28, (2009)

[11] Ibrahimbegovic A., *Nonlinear Solid Mechanics: Theoretical Formulations and Finite Element Solution Methods*, Springer, (2009)

[12] Ibrahimbegovic A., A. Boulkertous, L. Davenne, Modeling of reinforced-concrete structures providing crack-spacing based on XFEM, ED-FEM and novel operator split solution procedure., *Int. J. Num. Meth. Eng.*, 83, 452-481, (2010)

[13] Ibrahimbegovic A., A. Boulkertous, L. Davenne, M. Muhasilovic, A. Pokrklic, 'On modeling of fire resistance tests on concrete and reinforced-concrete structures', Computers and Concrete, vol 7. No. 4, 285-301, (2010)

[14] Ibrahimbegovic A., J.B. Colliat, M. Hautefeuille, D. Brancherie, S. Melnyk, Probability based size effect representation for failure of civil engineering structures built of heterogeneous materials, in (eds. M. Papadrakakis, M. Fragiadakis, G. Stefanou), '*Computational Methods in Stochastic Dynamics*', Springer, Berlin, 289-311, (2011)

[15] Ibrahimbegovic A., H.G. Matthies, Probabilistic Multiscale Analysis of Inelastic Localized Failure in Solid Mechanics, *Comp. Assis. Meth. Eng. Sci.*, 19, 277–304, (2012)

[16] Ibrahimbegovic A., R. Niekamp, C. Kassiotis, D. Markovic, H. Matthies, Code-coupling strategy for efficient development of computer software in multiscale and multiphysics nonlinear evolution problems in computational mechanics, *Advances Eng. Software*, 72, 8-17, (2014)

[17] Ibrahimbegovic A., A. Boujelben, Long-term simulation of large wind turbine structure for distributed loading describing long-term wind loads for preliminary design, Coupled Systems Mechanics, 7, 233-254, (2018)